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China Academy of Space Technology
CAST, 中国空间技术研究院

The Strategies of COTS Components on Selection, Validation and Usage and Some Typical Applications in Space Missions

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Topics

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- Instruction
- Selection Strategies of COTS Components
- Validation Methods for COTS Components
- Application Hardening Techniques
- Typical Application Case
- Summary

1. Instruction

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- **COTS Adoption in Space**
  - Commercial aerospace demand drives high-performance, low-cost COTS integration
  - E.g., SpaceX, China's Thousand Sail Constellation.
- **Challenges and Opportunities**
  - **Market Dynamics:** Aerospace-grade components trade volume <0.2% of global semiconductor market.
  - **Performance Gap:** Radiation-hardened (RH) components lag COTS by >10 years in processor performance.
  - **Key Drivers:** Cost reduction, rapid development cycles, and scalability for mass production.

2. Selection Strategies of COTS Components

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2.1 Requirement Analysis

- **Functional Performance:** Match mission requirements (e.g., power, interfaces, redundancy).
- **Environmental Adaptability:** Assess temperature range, radiation, vacuum, mechanical stress, etc.
- **Quality & Reliability:** Lifetime, failure rate, failure modes.

2. Selection Strategies of COTS Components

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2.2 COTS Component Product Selection

Category	Selection Element	Description
Inherent Charactistics	Function	• Ensure selected COTS components align with mission objectives. • Verify compatibility with peripheral circuits (power supply, drive circuits). • Assess industrial maturity of the overall circuit design and redundancy backup strategies.
	Performance	• Require technical/test data to confirm performance meets mission specifications. • Prioritize components with stable parameter values under extreme operating temperatures.
	Package	• Select packaging forms compatible with mature electrical assembly processes. • Avoid high-density assembly processes or restricted materials (e.g., lead-free coatings).
	Development tool	• Ensure availability of debugging tools (simulators, IDEs) and software libraries (OS, algorithms). • Validate the external interface of components, which can easily realize data.
Environmental adaptability	Temperature range	• Prioritize COTS components with the widest operational temperature range (vs. aerospace-grade counterparts).
	Environmental sensitivity	• Address risks like electrostatic/moisture sensitivity during installation, storage, and testing. • Implement preventive measures (e.g., shielding, controlled storage).
	Environment adaptability	• Assess adaptability to radiation, vacuum, mechanical stress, corrosion, and tin whisker risks. • Mitigate risks through material selection and design modifications.
Quality Reliability	Quality reliability	• Review screening reports, lot consistency, and failure rate data. • Validate supplier claims using sample tests for critical components. • Align component failure modes with mission reliability thresholds. • Conduct life-cycle testing for high-risk applications.

2. Selection Strategies of COTS Components

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2.3 COTS supplier selection

Select elements	Description

Feasibility of cost and cycle	• **Cost Analysis**:
	  • Evaluate historical purchase order data to assess cost-effectiveness (e.g., quality costs, sample losses).
	  • Align testing cycles with mission timelines to avoid delays.
	• **Optimization of delivery time**: Prioritize suppliers with proven track records of on-time delivery.

Guarantee of stable supply	• **Supply Chain Reliability:**
	  • Verify long-term availability of components during the mission lifecycle.
	  • Ensure a backup plans for discontinued products (e.g., substitutes or stockpiling).
	• **Storage and Replacement:** Confirm compatibility of stored components with future functional requirements.

Stability of manufacturing process	• **Process Consistency:**
	  • Assess impact of product/process changes on performance (e.g., material substitutions).
	  • Require suppliers to notify changes affecting specifications.
	• **Quality Assurance:** Validate lot-to-lot consistency through third-party audits.

Timeliness of technical support	• **Timely Technical Support:** Ensure 24/7 access to technical support. • **Rapid Issue Resolution:** Ensure that problems are quickly resolved

Traceability of the development process	• **Component Identification:**
	  • Track manufacturing sources via traceability codes (e.g., lot numbers, packaging week codes).
	  • Validate authenticity using device/package box/inner packaging markings.

3. Validation Methods for COTS Components

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3.1 Validation Requirement Analysis

- **Pre-Validation Analysis**:
  - Review **application history**, lot quality data, and radiation resistance test results.
  - Assess historical quality issues and component selection necessity.
- **Component Specifications**:
  - Confirm component model, packaging, quality level, and product lot details.
  - Determine if **radiation resistance evaluation** or system-level hardening is required.
- **Action Plan**:
  - Conduct **part-level** or **board-level validation tests** based on analysis outcomes.

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3.2 Part-Level Validation

- **Key Validation Steps**:
  - **Construction Analysis**:
    - **For Plastic Packaging**:
      - X-ray/C-SAM inspection, SEM analysis, bond strength tests.
      - Prohibited process checks (e.g., tin whiskers).
    - **For Ceramic Packaging**: Focus on material integrity and counterfeit detection.
  - **Radiation Resistance Evaluation:**
    - Perform **TID**, **SEE**, and **DD** tests.
  - **Additional Tests for New Components:**
    - Functional performance, simulated welding, limit testing, and lifecycle assessment.
- **Objective**: Identify prohibited processes, mitigate risks, and ensure aerospace suitability.

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3.3 Board-Level Validation

Board-Level Validation Includes as follows:

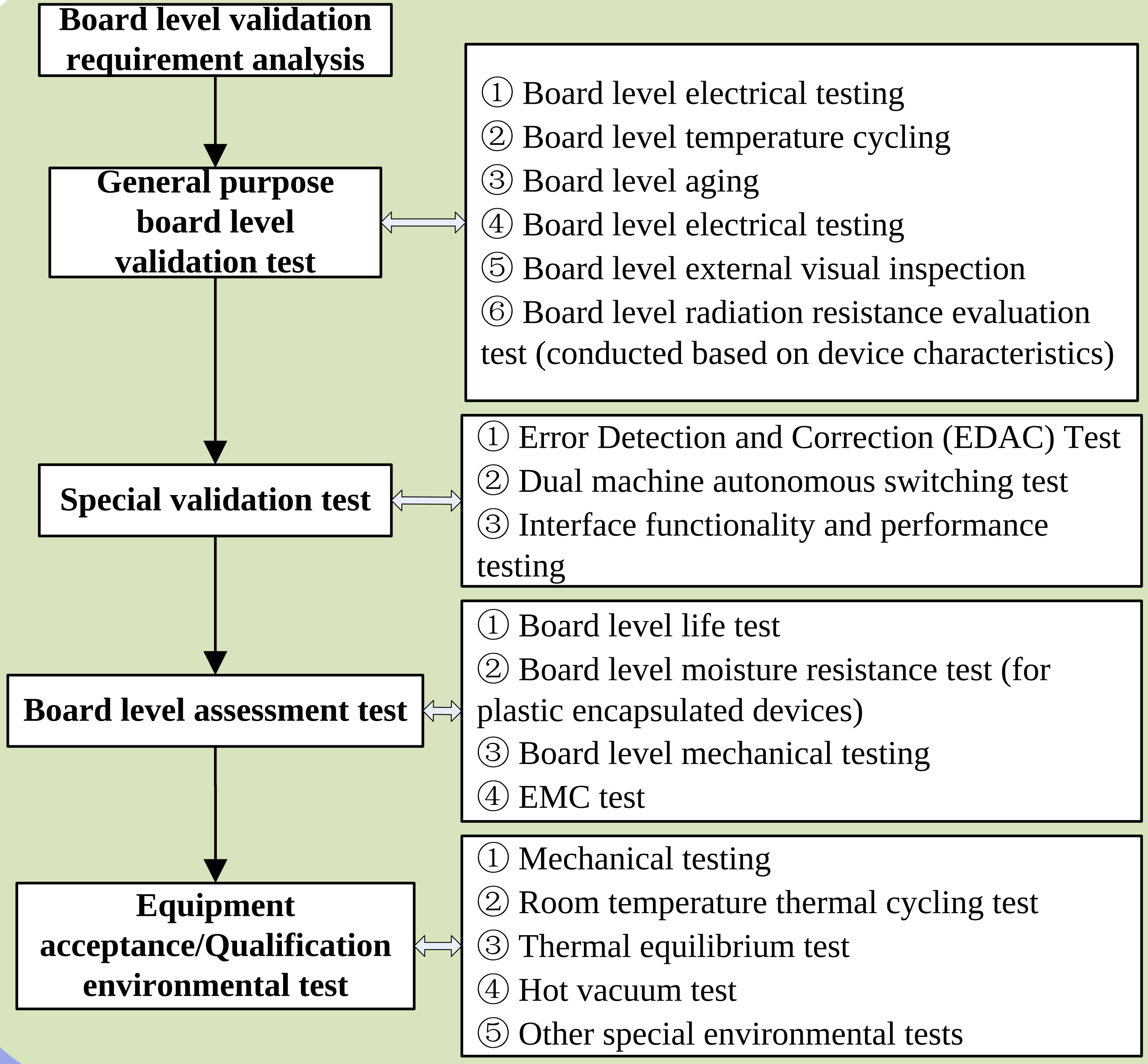
- **General Purpose Testing**:
  - Temperature cycling, aging tests, visual inspection, and radiation resistance checks.
- **Specialized Testing**:
  - **EDAC validation**, dual-system switching, interface robustness testing.
- **Assessment Testing**:
  - Lifetime simulation, humidity resistance, mechanical stress, and EMC compliance.
- **acceptance/qualification testing of accompanying onboard-units or systems :**
  - Mechanic test, thermal cycle, thermal-vacuum test, etc.

3. Validation Methods for COTS Components

3.3 Board-Level Validation

- **Validation Workflow**:

- **Key Strategies:**
  - Simplify part-level tests and integrate with board-level validation post-electrical assembly.
  - Try to combine onboard-units acceptance/qualification tests as much as possible.



4. Application Hardening Techniques

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4.1 Common Application Hardening Methods

- **Fault Tolerance Design**:
  - **Watchdog Timers:** Monitor system health and trigger resets on failure.
  - **EDAC (Error Detection and Correction):** Correct memory errors caused by radiation.
  - **Dual-Computer Redundancy:** Ensure continuity via backup systems.
  - **Triple Modular Redundancy (TMR):** Voting logic to mask errors in critical components.
- **SRAM Micro-Locking Mitigation**:
  - Detect errors in SRAM data areas and initiate automatic recovery.
- **System-Level Fault Monitoring**:
  - Real-time bus data monitoring to detect anomalies (e.g., overcurrent, SEL).
  - Automatic reset, power cycling, or isolation of faulty onboard-units.

4. Application Hardening Techniques

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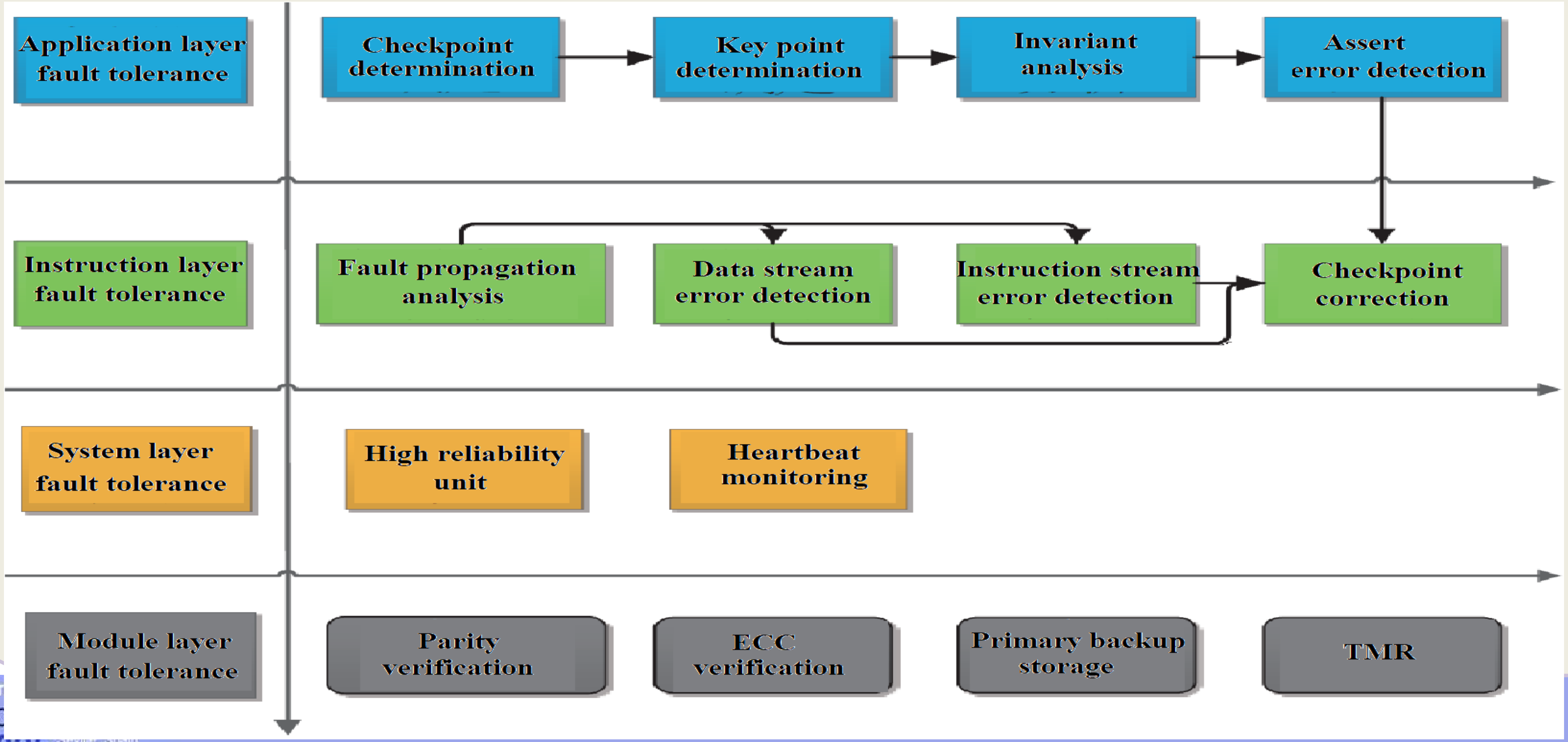
4.2 Cross-Layer Hybrid Fault-Tolerant Technology

- **Cross layer software fault-tolerant architecture.**



4. Application Hardening Techniques

4.2 Cross-Layer Hybrid Fault-Tolerant Technology

- **Objective**: Balance performance and reliability in harsh space environments.
- **Layered Architecture**:
  - **Application Layer:**
    - Lightweight error detection using invariant assertions.
    - Example: Algorithmic checks for data consistency.
  - **Instruction Layer:**
    - Time/space redundancy for error correction.
    - Example: Re-executing instructions on error detection.
  - **System Layer:**
    - **Heartbeat Monitoring**: High-reliability units send periodic status signals.
    - Example: Confirming CPU health via watchdog signals.
  - **Module Layer:**
    - Secure storage of error logs and recovery data.
    - Example: Trusted storage for fault recovery parameters.

4. Application Hardening Techniques

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4.3 Radiation-Resistant Application Hardening

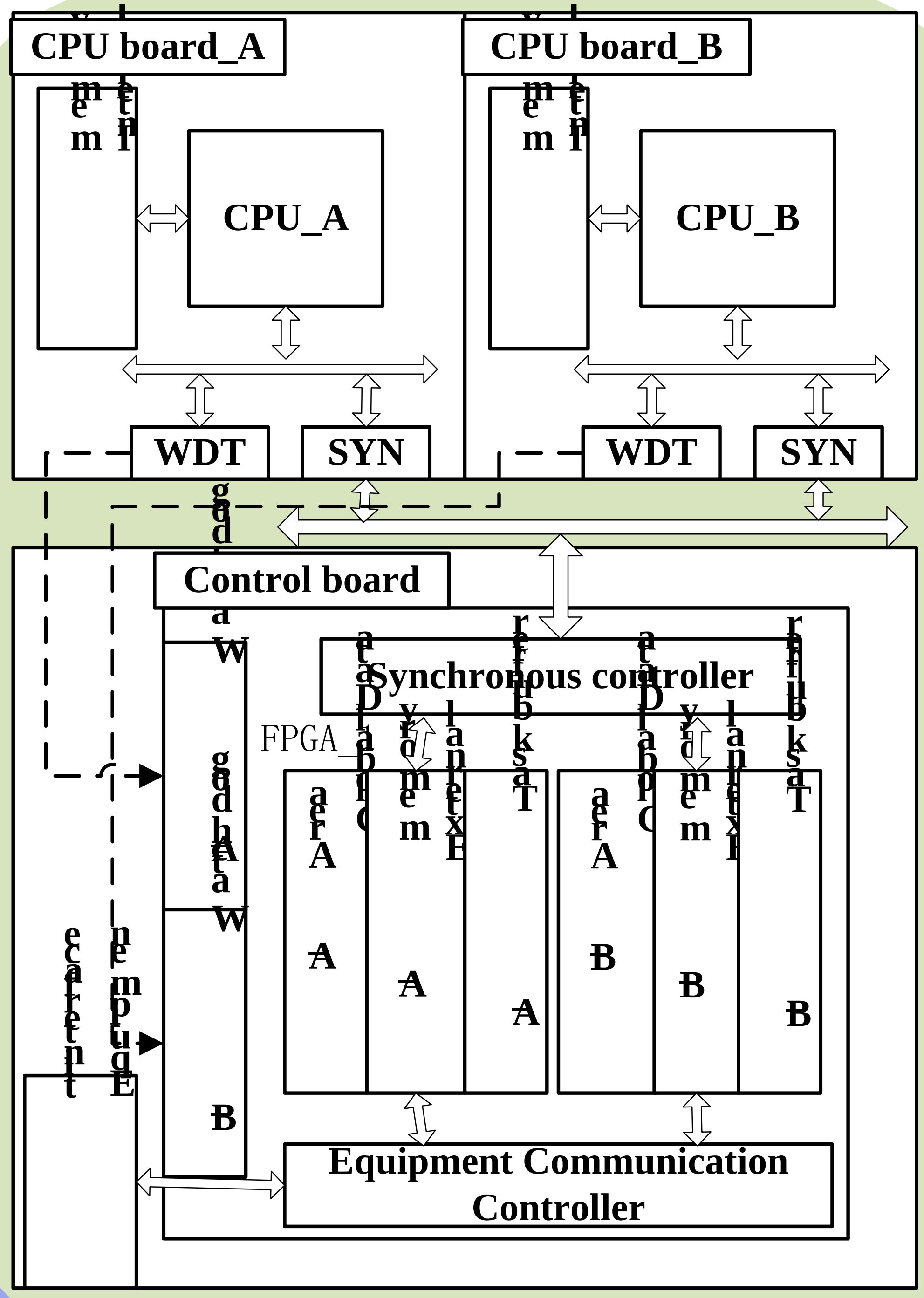
- **Single-Event Effects (SEE) Mitigation**:
  - **Watchdog Circuits:** Detect and recover from transient faults.
  - **Redundancy + EDAC:** Protect digital interfaces (e.g., TMR for memory modules).
  - **Current Limiting:** Prevent Single-Event Burnout (SEB) in power terminals.
- **Single-Event Latchup (SEL) Prevention**:
  - Real-time current monitoring and power cutoff.
  - Anti-latchup circuits for critical components.
- **Total Ionizing Dose (TID) Mitigation**:
  - Component layout optimization and localized shielding.

4. Application Hardening Techniques

4.3 Radiation-Resistant Application Hardening

Case Study: Dual-redundant Fault-Tolerant System

- **Design**:
  - Two redundant CPU boards + control board.
  - TMR for FLASH/SRAM storage modules.
- **Performance**:
  - SEU rate in LEO: ~10^{-7}/(bit·day).
  - TMR improves FLASH reliability by $10^{6}\times$ in daily operation.



5. Typical Application Case

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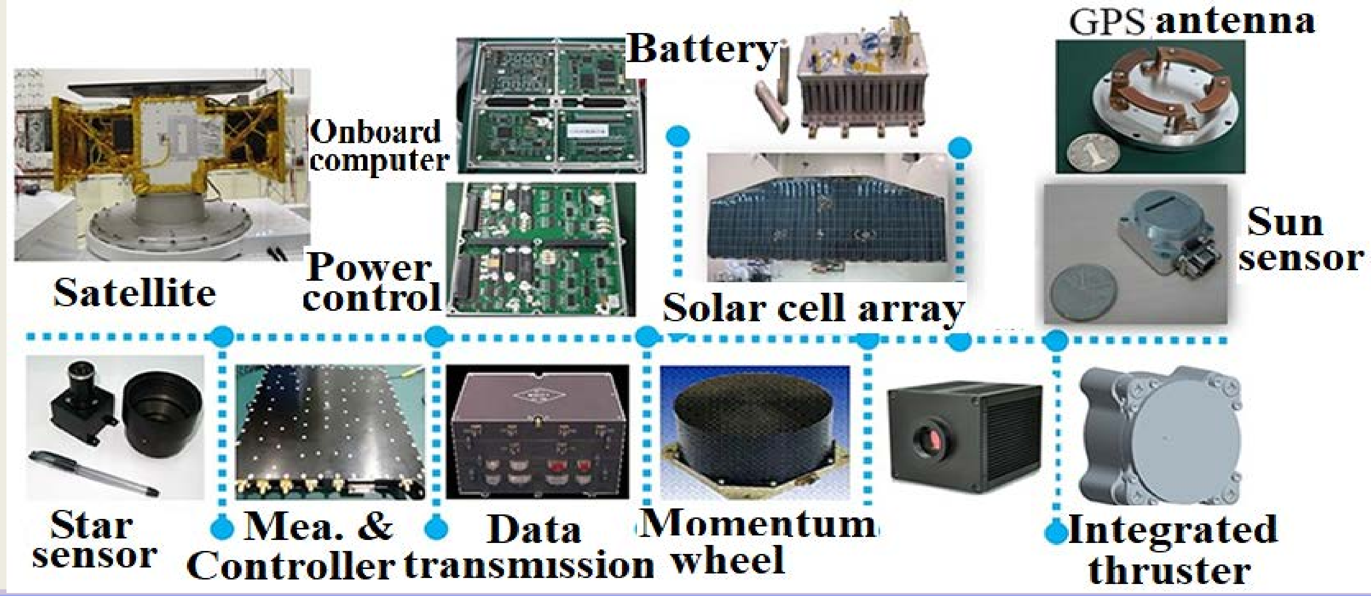
5.1 COTS Components Integrated into a Satellite

- **Key COTS Components**:
  - Industrial-grade computers, Li-ion batteries, monocrystalline silicon solar cells.
  - Magnetometers, industrial cameras, measurement/control modules, data transmission modules.
- **Design Philosophy**:
  - Selected for **stable performance**, **low power consumption,** and **interface compatibility**.



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5.2 COTS Selection and Validation Requirement Analysis

- **Supplier and Product Screening**:
  - Evaluated 25 advanced industrial technologies and 18 new product types.
  - Conducted **200+ tests** on newly selected COTS components.
- **Targeted Testing**:
  - **Space Environment Adaptability**: Radiation, thermal vacuum, mechanical stress.
  - **Specialized Validation:** Error Detection and Correction (EDAC), dual-system redundancy.

5.3 Board-Level Validation Tests

- **Total Ionizing Dose (TID) Test**:
  - 4 multi-channel switches damaged → replaced with radiation-tested alternatives.
- **Other Tests**:
  - All interface, functionality, and performance tests passed.
  - Early failures and defective components eliminated through pre-screening.

Validation Category	Test Items	Objective
Space environment adaptability assessment	Total Ionizing Dose (TID) Test	Identify weak components under radiation.
	Single-Event Test	Validate the computer's ability to resist SEE .
Special validation test	EDAC (FPGA-Based) Test	Verify error detection/correction capabilities.
	Flash Fault Tolerance Test	Assess Flash memory reliability under faults.
	Dual onboard-units Switching Test	Validate redundancy and autonomous switching logic.
Acceptance level/qualification level environmental testing	Mechanical Testing	Confirm structural integrity under vibration/shock.
	Thermal Cycling Test	Validate manufacturing processes and identify early failures.

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5.4 COTS In-Orbit Performance

- **Successful Operation**:
  - Satellite has functioned normally for **over 2 years** in orbit.
  - Validated through **ground tests, EMC, thermal,** and **magnetic property tests.**
- **Key Achievement**:
  - COTS components met mission requirements, demonstrating cost-effectiveness and reliability.

6. Summary

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Feasibility of COTS in Space: Success hinges on comprehensive strategies for selection, validation, and usage.

- **Selection Strategy**:
  - Align with mission requirements (orbit, lifespan, reliability).
  - Evaluate 8 critical product criteria (e.g., functional performance, radiation tolerance).
  - Prioritize suppliers using 5 key factors (cost, stable supply, process stability).
- **Application Validation**:
  - Focus on radiation performance for mature COTS components.
  - Integrate board-level validation (e.g., thermal cycling, EMC tests) with system-level requirements.
- **Usage Hardening (Redundancy & Fault Tolerance) :**
  - Implement dual-computer backup, TMR, and EDAC for critical systems.
  - Optimize application hardening (e.g., current limiting, SEL protection).

Thank you for your attention

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